

On the Discovery of Strong Magnetic Field in HD 34736 Binary System*

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Abstract. We present the results of a study of the star HD 34736. The spectropolarimetric observations carried out at the 6-m telescope showed the presence of a strong variable longitudinal magnetic field, exceeding -4500 G. The analysis of the HIPPARCOS photometry gives a set of possible periods of the brightness variability of the star, of which 0^d3603 is preferred. The variable radial velocity of spectral lines of the star and some signatures of lines of at least one other component show that HD 34736 is a double short-period system. Modeling of the spectra allowed us to estimate the effective temperature T_{eff} of the stars ($13\,700$ and $11\,500$ K) and their projected rotational velocities $v \sin i$ (73 and ≥ 90 km s $^{-1}$). The analysis of all the available information about the star allows us to hypothesize that the object of study is a close, possibly interacting binary system.

Key words: stars: magnetic field—binaries: close—stars: fundamental parameters—stars: chemically peculiar—stars: individual: HD 34736

1 INTRODUCTION

The study of magnetic properties of early-type stars provides a unique opportunity to study in detail the features of the processes of their evolution, formation and variation of the magnetic field strength with age. This is primarily due to the rapid evolution of massive stars. A major part of B-type stars is found in open clusters and associations, and hence the accuracy of determination of their age is significantly higher than for the field stars. All these factors have facilitated the start of a large observational program called *Magnetic Fields of Massive Stars* at the Special Astrophysical Observatory of Russian Academy of Sciences (SAO RAS). The conceptual issues of the program, formulating the problem, and selecting the objects of study are presented in the paper by Romanyuk and Yakunin [1]. Spectropolarimetric observations with the 6-m BTA telescope within this program started at the end of 2010 and are still ongoing. Recently, our research has been focused on the study of the already known and the search for new stars with magnetic fields in the nearby Ori OB1 association. In the course of the survey of chemically peculiar (CP) stars of the association, the star HD 35298 was studied in detail [2]. The observations of poorly-studied CP stars of the association allowed us to detect the signs of magnetic field in four stars. This paper is devoted to the features of one of them, HD 34736.

A chemically peculiar star HD 34736 ($m_V = 7^m82$) with silicon abundance anomalies [3] is a member of the Ori OB1 association (sub-group C) [4]. A large amount of the photometric data (the systems *UBV* [5], Strömgren [6], Maitzen Δa [7], Walraven [8]) provides confident estimates of the

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Table 1: Log of observations of HD 34736 and standard stars

Star	HJD 2450000+	λ , Å	S/N
HD 34736	6589.4929	4402.6–4955.8	250
53 Cam	6589.5569		270
<i>o</i> UMa	6589.5578		690
HD 34736	6639.4980	4428.3–4983.7	220
α^2 CVn	6639.6643		1150
HD 33256	6639.4717		270
HD 34736	6644.4389	4427.3–4982.3	300
53 Cam	6644.5097		300
<i>o</i> UMa	6644.5171		830

main characteristics of the star. According to the Geneva photometry indices, North and Kramer [9] predict the surface magnetic field of the star of $B_s \approx 1.9$ kG. However, the literature contains no evidence on the direct measurement of this magnetic field.

Based on the analysis of data presented in the work of Brown et al. [4], the catalog of CP stars by Renson and Manfroid [10], and other literary sources, we have selected the star HD 34736 as a candidate for the spectropolarimetric observations with the 6-m telescope of the SAO RAS [11]. Three observations of the star were performed to date, their description is contained in Section 2. The results of measurements of the Zeeman effect in the spectra of the star and determining the magnitude of its magnetic field are shown in Section 3. Section 4 is devoted to the estimation of the main physical parameters of HD 34736. The final Section 5 discusses the results we have obtained.

2 SPECTROSCOPIC OBSERVATIONS AND PROCESSING

For the first time the star HD 34736 was observed by us on the 6-m telescope in October 2013. In December of the same year, two more sets of spectra were obtained. An excerpt from the log of observations is presented in Table 1. It provides the data on the Julian date (HJD) at the time of mid-exposure, the spectral range, and the signal-to-noise ratio of the registered spectra of polarized light. The observations were carried out on the Main Stellar Spectrograph (MSS) of the BTA, the description of the optical scheme of which and its instrumental capabilities can be found on the web page of the device.¹ The spectrograph was used in the spectropolarimetric mode using a circular polarization analyzer and a slit unit with a double image slicer [12]. The polarization analyzer has a $\lambda/4$ phase plate, which has two fixed positions at 90° relative to each other. The characteristic property of this analyzer is that the resulting spectrum of circularly polarized light of a star should be appropriately calculated as the average of two exposures at different positions of the phase plate. The averaging allows to effectively get rid of residual traces of cosmic particles and also to remove the possible instrumental polarization, as the spectra of oppositely oriented polarized light are registered at the same regions of the detector. In all the cases, the spectra were registered using the E2V CCD 42-90 chip sized 2048×4600 elements. The average inverse linear dispersion of the recorded spectra is about 0.1215 Å per pixel.

A set of calibration images needed to perform the extraction of spectral data was typical for such problems and included the images of zero exposure frames (bias), spectra of the continuous

¹ <http://www.sao.ru/hq/lizm/mss/en/>

Table 2: The results of determination of the longitudinal magnetic field of HD 34736 and standard stars. Columns 3–5 represent the results obtained by measuring the centers of gravity of spectral lines, approximating function minima and by the linear regression method [14], respectively. The number of measured lines is indicated in the parentheses

Star	HJD 2450000+	$B_e(\text{COG}) \pm \sigma, \text{ G}$	$B_e(\text{AF}) \pm \sigma, \text{ G}$	$B_e(\text{regres}) \pm \sigma, \text{ G}$	Sp
HD 34736	6589.4929	-3500 ± 440 (36)	-4380 ± 720 (13)	-2147 ± 135	B9
53 Cam	6589.5569	740 ± 70 (228)	690 ± 80 (203)	935 ± 50	A2p
<i>o</i> UMa	6589.5578	-59 ± 50 (335)	-80 ± 60 (328)	-80 ± 50	G5
HD 34736	6639.4980	-160 ± 530 (33)	-160 ± 1170 (12)	782 ± 170	B9
α^2 CVn	6639.6643	-680 ± 50 (242)	-760 ± 50 (159)	-710 ± 50	A0
HD 33256	6639.4717	-33 ± 50 (205)	-30 ± 50 (188)	-50 ± 50	F2
HD 34736	6644.4389	-4580 ± 560 (45)	-5080 ± 1040 (16)	-3790 ± 140	B9
53 Cam	6644.5097	-3340 ± 110 (193)	-3460 ± 120 (169)	-2930 ± 50	A2p
<i>o</i> UMa	6644.5171	-10 ± 60 (266)	-10 ± 60 (262)	-10 ± 50	G5

spectrum source for the subsequent flat-fielding, and a comparison spectrum, for which we have used the emission spectrum of the Th-Ar lamp.

All the procedures related to the processing and extraction of one-dimensional spectra were ran in the ESO-MIDAS using the LONG context and a set of programs written by D. Kudryavtsev [13]. The spectra were normalized to the continuum level, and the wavelength scale was corrected for the orbital motion of Earth.

3 MAGNETIC FIELD OF HD 34736

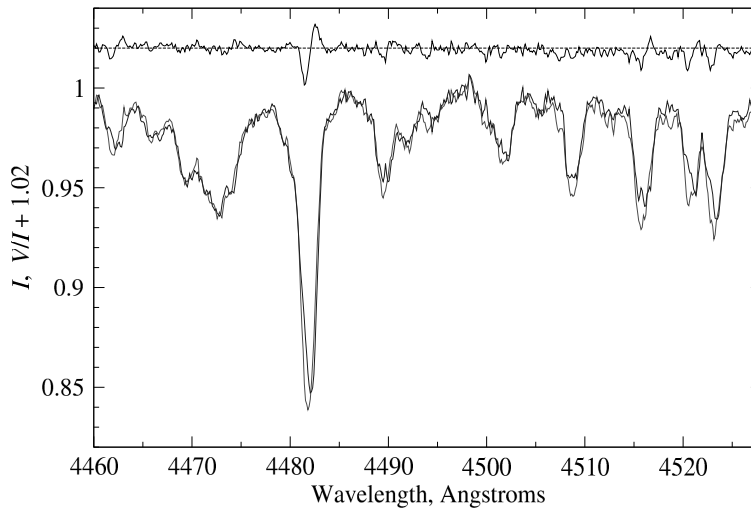


Figure 1: The right-hand and left-hand circularly polarized spectra of the star HD 34736 in the region of the Mg II 4481 Å line. The normalized Stokes V parameter, shifted along the y -axis, is given on the top.

The spectra of HD 34736 are characterized by complex profiles of most of the lines (Fig. 1):

the same lines appear differently in the spectra of right and left-hand circular polarizations. This phenomenon indicates the complex geometry of the global magnetic field of the star and its considerable strength. The stellar spectrum relatively poor in lines is a consequence of two factors: high effective temperature (13 800 K, according to [4]) and rapid rotation of the star. Our experience shows that in case of spectra with complex line profiles, different longitudinal field methods show different results (see, e.g. [2]). Sometimes these differences prove to be statistically significant. In order to maximize the accuracy of our conclusions, we have at the same time used the method for measuring the Zeeman effect consisting in finding the shifts between the line profiles in the spectra of the left and right-hand circular polarizations, and the method of longitudinal field estimation proposed by Bagnulo et al. [14]. In practice, we can take several different quantities for the spectral line wavelength. For example, the wavelength of the center of gravity of a profile or the wavelength of the approximating function minimum when it comes to absorption lines. The Gauss function is most commonly used for the latter. It is easy to understand that in the case of complex line profiles, distorted, for example, by the crossover effect, the wavelength of the spectral line center will be different. This discrepancy affects the results and is especially critical when we try to measure the weak B_e fields.

Notwithstanding the fact that the process of obtaining and processing of the spectral data that we implement on the 6-m telescope is aimed at the maximum account of the instrumental effects, we perform additional verification of the results of our measurements. Along with the studied stars, we obtained the spectra of standard stars every night. To verify the absence of instrumental shifts of spectral lines, we use the stars of late spectral classes with a big number of narrow lines—the so-called zero-field standards. The second group of standards consists of those CP stars, the magnitudes and polarities of whose magnetic fields are well known. In the observations described we used the standard stars 53 Cam, α^2 CVn (magnetic) and HD 33256, σ UMa (zero-field standards).

The summary Table 2 contains the results of the longitudinal magnetic field measurements for the studied star and standard stars. Columns 3 and 4 in parentheses indicate the number of measured lines.

A comparative analysis of the Table 2 data allows us to confidently infer the presence of a magnetic field on the surface of HD 34736. At one night the longitudinal field of the star was measured close to zero; however, there is a crossover effect (the difference in the shapes of lines of the right- and left-hand circularly polarized spectra) which happens when the star is observed from the magnetic equator. All the three measurements of the stars without magnetic fields gave a zero result within the measurement errors, thus confirming the absence of significant instrumental effects. The measured longitudinal field of the 53 Cam and α^2 CVn stars is in good agreement with the expected values, presented in the form of dependencies, for instance, in [15].

As for the accuracy of measurements, it is worth noting the following. Two methods for determining the field based on the measurement of shifts of the polarized components of spectral lines give a result comparable in accuracy (columns 3 and 4 of Table 2). The linear regression method (column 5), described in [14], has some restrictions. The most significant restriction concerns the weak field mode—the method is applicable when the influence of the Zeeman effect on the shape of spectral line profiles is significantly weaker than the other broadening mechanisms. In the case of the star HD 34736, where the projected rotational velocity amounts to 73 km s^{-1} , the weak field approximation will be valid up to the longitudinal field values of 4–5 kG, depending on the lines. This means that the B_e values from column 5 are valid. The second restriction of the linear regression method is due to the quality of spectrum normalization to the continuum level. Since the normalization cannot always be done quite accurately in all parts of the spectrum, we believe that the errors can be somewhat underestimated for some measurements of magnetic stars indicated in column 5.

4 PHYSICAL PARAMETERS OF THE STAR

In the literature one can find some estimates of the effective temperature and luminosity of the star. Our independent estimates of T_{eff} agree well with the data of Brown et al [4] (13 800 K) and Glagolevskij [16] (12 800 K).

We have determined the effective temperature of the star and its surface gravity with the use of the existing calibrations for the photometric indices in the Strömgren and Geneva systems.

The index values of the first system are taken from [5] and [6]. The calibrations from Napiwotzki et al. [17], implemented in the `uvbybeta_new` code, give two effective temperature values: 13 620 K and 13 180 K. The latter corresponds to the calibration of the photometric index $[u-b]$, used basically for the stars with $T_{\text{eff}} > 9500$ K. The $\log g$ value is equal to 4.31, according to Napiwotzki et al. [17]. The application of dependences to the photometric indices described in [18] gives $T_{\text{eff}} = 13\,756$ K, $\log g = 4.21$.

For the photometric indices of the Geneva system, we have used the calibrations from [19]. The given method for determining the effective temperature is sensitive to the interstellar extinction, which, accounting for the far distance of the star ($\pi = 1.78 \pm 0.94$ mas [20]) and its position in the young association, can reach significant values. Since we have spectra in our disposal with only a limited wavelength range, we attempted to estimate the $E(B-V)$ color excess from the photometry. The temperature calibrations by Moon and Dworetzky [18] for the *uvby* photometric system allow us to estimate the color excess $E(b-y) = 0^{\text{m}}012$. Then we find $E(B-V) = 0^{\text{m}}017$ and $E(B2-V1) = 0^{\text{m}}015$, using the $E(B-V) = 1.43 E(b-y) = 1.14 E(B2-V1)$ relations that link the *UBV*, Strömgren, and Geneva photometric systems. Another method to estimate the interstellar absorption values is the *UBV* photometry in case the $(U-B)$ and $(B-V)$ indices are known. For HD 34736 the relationship $E(B-V) = (B-V) - 0.332 Q$ is true, where the Q parameter is defined as

$$Q = (U - B) - 0.72 (B - V) - 0.05 (B - V)^2.$$

This method gives a significantly higher value of $E(B-V) = 0^{\text{m}}047$. A similar result is obtained if we follow the work of Brown et al. [4], where all the data were obtained from the photometric indices of the Walraven system: $E(B-V) = 0^{\text{m}}038$. For the further calculations we took the average of the last two quantities: $E(B-V) = 0^{\text{m}}043$. The interstellar absorption in the *V*-band is $A_V = 3.11 E(B-V) = 0^{\text{m}}134$.

The GCPD catalog of photometric data² contains information on the photometry of HD 34736 in the Geneva system. After applying the photometric calibrations from Künzli et al. [19], we have obtained two parameter sets depending on the metallicity of the star: $T_{\text{eff}} = 13\,500$ K, $\log g = 4.13$ for $[M/H] = 0$, and $T_{\text{eff}} = 13\,200$ K, $\log g = 4.20$ for $[M/H] = +1$. The color excess $E(B2-V1) = 0^{\text{m}}038$.

We can see that all the photometric estimates of the effective temperature of the star are in good agreement, but a comparison of the observed H_β hydrogen line profile with the calculated one testifies about a slightly higher temperature. Therefore, we finally determine T_{eff} as $13\,700 \pm 400$ K. The shape of the H_β line can be satisfactorily described in the assumption that the surface gravity is equal to 4.15 ± 0.15 dex. This value is only 0.05 dex smaller than the average photometric estimate of $\log g$.

The star HD 34736 belongs to moderately fast rotators. From the measurements of the profile of the Fe II 4508 Å line, which is the least sensitive to the magnetic field, we find $v \sin i = 73 \pm 7$ km s⁻¹. The specified value implies the period of stellar rotation shorter than three days. To determine the period of stellar rotation, we attempted to analyze the photometry data obtained by the HIPPARCOS mission and in the ASAS survey [21]. Using the Dimming method [22], we can get a few values of the likely period, from 0.3 to 1.6 days (e.g., Fig. 2). With some of them we can satisfactorily reconcile the values of the longitudinal field of the star. However, we have to bear in mind that

² <http://obswww.unige.ch/gcpd/>

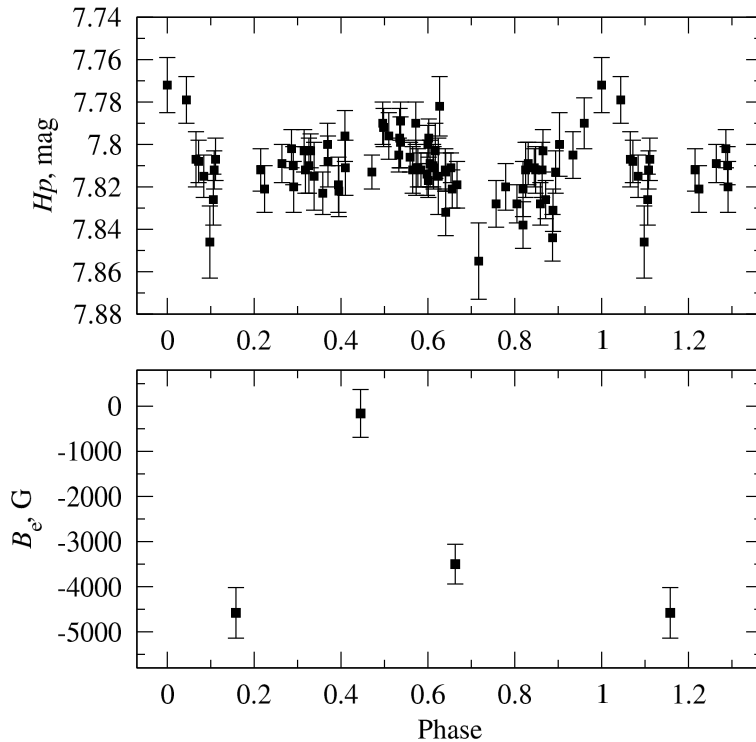


Figure 2: Photometric variability of HD 34736 according to the HIPPARCOS data with the period of 0^d.3603 (top) and our measurements of the longitudinal field B_e of the star, phased with the same period (bottom).

three measurements of B_e are not enough to draw firm conclusions about the period. In any case, only the further spectropolarimetric observations of the star, given the longitudinal field variability amplitude might yield the most accurate idea about the variability of HD 34736.

An important fact is a note in the HIPPARCOS catalog that the variability of the star is caused by its duality. We get a direct confirmation of the presence of another star from the analysis of the spectra. Firstly, from the three spectra obtained by us, the radial velocity of the star significantly differs in two cases (Fig. 3): $+31 \pm 6 \text{ km s}^{-1}$ and $-41 \pm 5 \text{ km s}^{-1}$. Secondly, the spectrum of October 24, 2013

(HJD 2456589.4929) in the region of the H_β line bears the features of a hydrogen line belonging to the second star (Fig. 4). The asymmetry manifests itself in the majority of other lines too (Fe, Cr, Mg, and Si). We were able to describe the H_β line shape presenting it by a combination of two lines. The best agreement was reached in an assumption that the primary component of the system is characterized by $T_{\text{eff}} = 13\,700 \text{ K}$ and $\log g = 4.0$, while the secondary component is somewhat cooler: $T_{\text{eff}} = 11\,500 \text{ K}$ and $\log g = 4.0$. We have earlier found the projected rotational velocity of the hotter star ($v \sin i = 73 \text{ km s}^{-1}$). It is more difficult to judge on the rotation of the second star. The wavelength range of our spectra has virtually no lines that could be confidently attributed to the cooler star, except for the strongest line Mg II 4481 Å. The degree of broadening of the Mg II and H_β lines of the second component corresponds to the rotation of the star at $v \sin i$ value of not less than 90 km s^{-1} . The radial velocities of the lines of the primary and the secondary components amount to -30 and $+110 \text{ km s}^{-1}$ respectively. The lower limit of the accuracy of finding $v \sin i$ of the cold component amounts to 15 km s^{-1} . We estimate the accuracy of determining the radial velocities of the components as $3\text{--}8 \text{ km s}^{-1}$. However, if we assume a more complex configuration of stars in this system (three stars or a star with a shell/magnetosphere), all the estimates of the

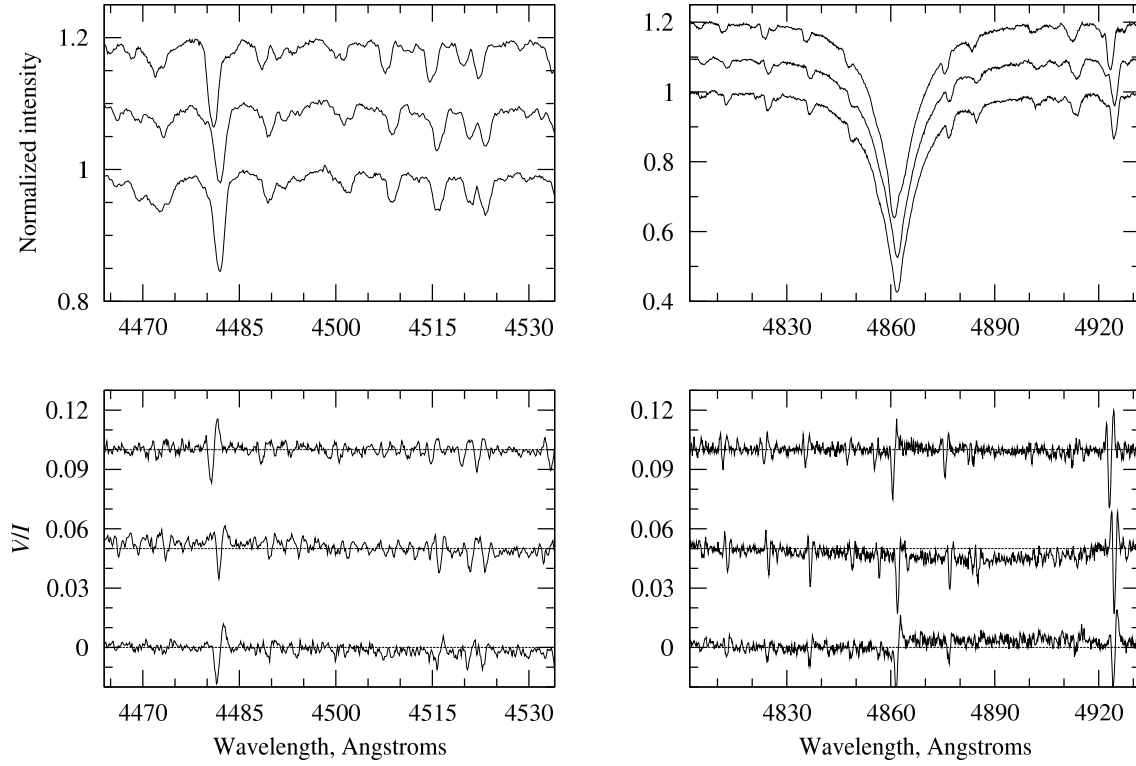


Figure 3: Two regions in the spectrum of HD 34736, demonstrating the variability of the magnetic field and radial velocity. The upper graphs contain the intensity spectra I , normalized to the continuum, the bottom graphs are the normalized spectra of the Stokes V parameters. The spectra for different rotation phases are given with the shift along the y axis, from bottom to top: 0.15, 0.45, and 0.65. The phases are calculated in accordance with the period $0^{\text{d}}.3603$.

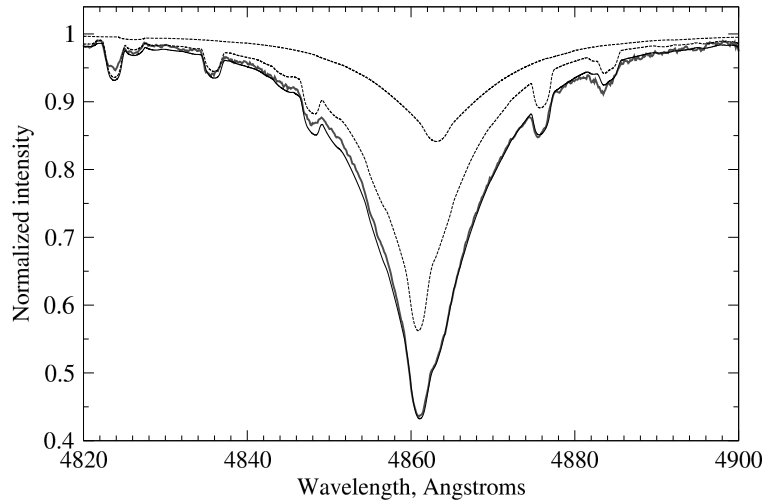


Figure 4: The spectrum of HD 34736 in the region of the H_{β} hydrogen line with indications of the line of the second component. The smooth thin black line is the synthetic spectrum calculated with the parameters mentioned in the text. The dotted lines correspond to individual spectra of the binary system.

parameters of the secondary component should be considered as their upper value.

Quantitative estimates of the abundance of chemical elements in the atmospheres of the binary system components can be made only after the accumulation of additional observational material and its analysis. In a qualitative manner we can state the following about the binary system: the main component is a chemically peculiar star, the secondary is apparently the spectral type B9 star with a normal chemical composition of the atmosphere. The abundance of strengthened Fe, Cr, Ti lines in the observed spectrum supports this conclusion. We have identified several Nd III lines. Modeling of the silicon lines even in the first approximation detects significant discrepancies between the depth of the Si II 4621 Å and Si III 4552, 4567, 4574 Å lines. The calculation of theoretical spectra was based on the use of data on the spectral lines from the VALD database [23, 24] and was carried out using the **Synthmag** code [25]. The magnitude of the microturbulence velocity was assumed to be typical of CP stars within this temperature range: $\xi_{\text{micro}} = 1.5 \text{ km s}^{-1}$. It should be noted that the rapid rotation of the secondary component greatly simplifies the analysis of the magnetic field of the main star, since the strongly broadened lines are practically invisible in the combined spectrum. A much greater contribution to the approximation accuracy of individual line profiles is made by the magnetic field configuration. In our calculations the magnetic field at the surface of the first star was supposed to amount to 12 kG, but we cannot exclude a more complex geometry which is common in CP stars of the B7–B9 spectral classes. In the latter case the surface field of the star may prove to be larger. A distortion in the shapes of profiles of most lines is noteworthy. These distortions can be explained as an overlap of another spectrum, close to the main component of the system in its composition and effective temperature but with no radial velocity shift. We are confident that the discovered effect is not due to the extraction errors but reflects the physical effect. A possible explanation for all the listed facts is given in the next section.

5 DISCUSSION

The new magnetic star we have discovered, HD 34736, is a unique object. Three measurements of polarized spectra show a variable magnetic field, the magnitude of the longitudinal component of which varies from 0 to almost -4500 G . Along with the magnetic field we also observe a spectral variability. The character of the latter indicates the presence in the spectrum of the lines belonging to the second star, somewhat cooler ($T_{\text{eff}} = 11500 \text{ K}$). The study of the HIPPARCOS photometry data allows to select several possible periods of brightness variability, where the most likely of them is 0^h36^m03^s. Apparently, this value is the orbital period of the binary system. Radial velocities of the components, obtained by decomposing the spectrum into components, support this assumption. All our results concerning the modeling of the spectrum of the second star are preliminary. For a more detailed analysis new observations are required in order to measure the radial velocity of the system and the longitudinal magnetic field of the star. The rotation period of the magnetic star in the HD 34736 system can only be determined after the analysis of a sufficient number of measurements of its magnetic field. To make the final conclusion on the presence of a magnetic field in the second star, circularly polarized spectra with a very high signal-to-noise ratio are required.

We have tried to divide the spectrum of the star into the components which allowed us to estimate the effective temperatures, surface gravity, and rotation velocities of both components. We could obtain the preliminary value of $v \sin i = 130 \text{ km s}^{-1}$ for the secondary component only from one line of Mg II 4481 Å, which manifests itself well in the right wing of the line of the composite spectrum from October 23, 2013. If we assume that the main contribution to the observed spectrum is made by two stars with effective temperatures of T_{eff} equal to 13 700 and 11 500 K, a larger part of the observed hydrogen H_{β} line can be described well, except for its short-wavelength wing. At the same time, the shapes of many lines reveal features that can be interpreted as traces of the third spectrum with the chemical composition and temperature of the main star. The nature of

this spectrum remains to be clarified, but we can now confidently say that its manifestation is not a result of processing errors: the short-wave wing of the composite line H_β can be described with high accuracy only in the presence of the third spectrum. In our opinion the physical explanation of such a complex spectrum may be as follows. The star HD 34736 represents a short-period binary system, the main component of which, with a higher temperature, is a magnetic star. The stars make one revolution around the common center of gravity in about 0^d.3603. This results in substantially different radial velocities of individual components. The brightness curve of HD 34736 (Fig. 2) has a second minimum at phase $\varphi \approx 0.73$ which can be caused by the spatial orientation of the system relative to the observer and the dimension ratio of stars. It is very likely that interchange of matter takes place in this system, forming a shell or a tail. We detect the traces of this matter in form of the third component of the spectrum. The presence in it of the same lines as in the spectrum of the main star can tell of the origin of matter of this shell. The spectral range we observe bears no prominent signs of emission. However, Leone [26] states that HD 34736 is a confirmed X-ray source. The X-ray activity in the case of main-sequence B-type stars is often a sign of either the presence of a powerful magnetosphere or close interacting components. It is possible that HD 34736 combines both cases. Therefore, the further study of this star can be extremely important to address the origin and evolution of close binary systems possessing a strong magnetic field. But at the same time, we cannot exclude other possible explanations of observations, since the total data set is still little.

Acknowledgments

This work was partially supported by the Russian Foundation for Basic Research (grant no. 12-02-00009-a). The observations on the 6-meter BTA telescope were conducted with the financial support of the Ministry of Education and Science of the Russian Federation (state contracts no. 14.518.11.7070, 16.518.11.7073).

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Translated by A. Zyazeva